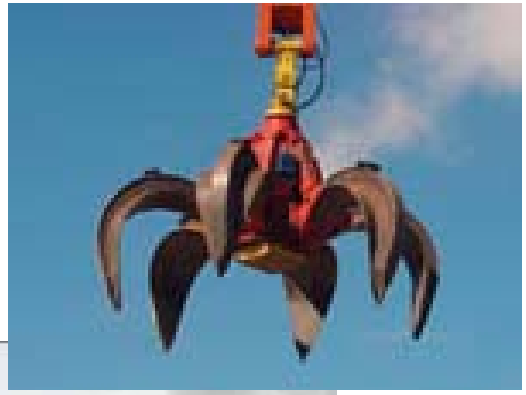
Introduction



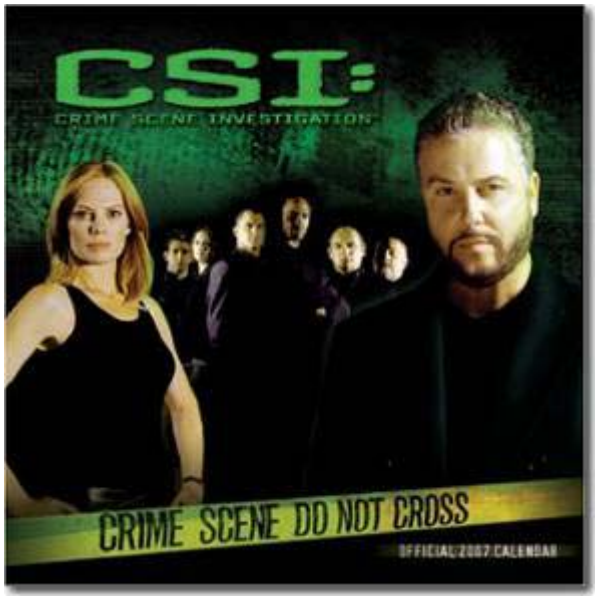
November 2007
Uranium intercepted through intelligence, Pribeník, SK

November 2008
Uranium detected at scrap metal recycling facility, Rotterdam, NL

Questions:

1. How did the material get there?
2. Origin of the material ?
3. Intended use of the material?
4. Age of the material?

Introduction



Detection and Nuclear Forensic Analysis of Uranium Materials

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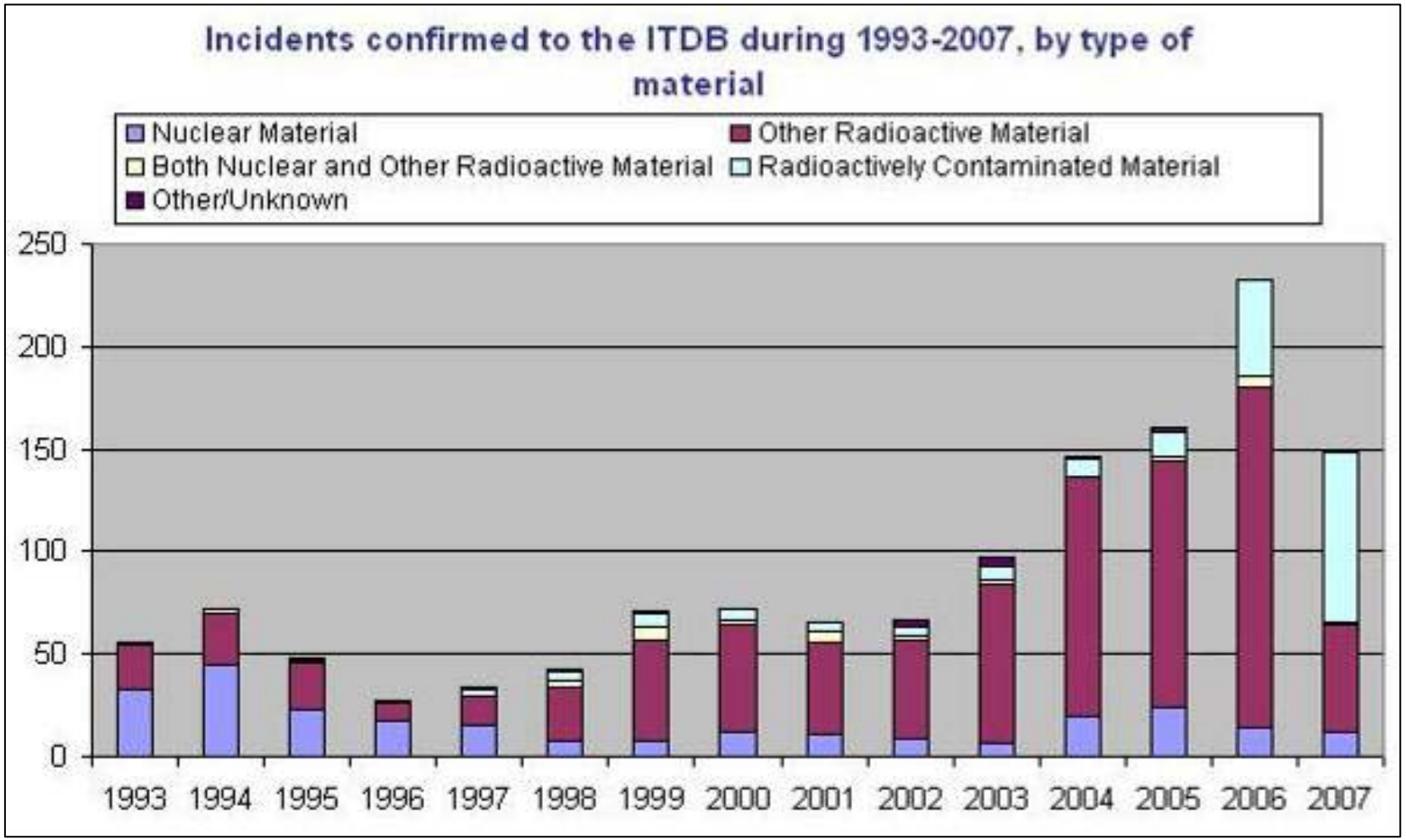
- About ITU
- Introduction
- Response
- Nuclear Forensics Methodology
- Recent Example
  - Pellets seized in northern Germany (2007)
  - Uranium detected at scrap metal yard (2006)
- Conclusion

Illicit Trafficking (all types) incidents 1993-2007

(source: IAEA)



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Response to illicit trafficking

Detection

Detection equipment, intelligence

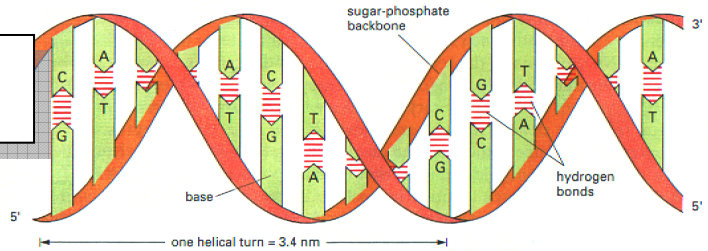
Nuclear Material (U, Pu, reactor or weapons grade) or other radioactive material (^{60}Co,^{137}Cs, ^{192}Ir,…)

Categorization

Nuclear Forensics

Source Attribution

Classical Forensics



Aims at identifying suspect **individual** using information adherent to the pieces of evidence:

- Fingerprints
- **"genetic fingerprint"**
- Fibre
- Hair
- Residues of explosives

Objective

Solve criminal case and put criminal individual to jail

Aims at identifying origin and intended use
using information inherent to the (nuclear) **material**:

- Isotopic Composition
- Elemental Composition
- Impurities
- Macroscopic appearance
- Microstructure
- Decay Products

Objective

Improve safeguards and physical protection measures at place of theft or diversion to prevent future thefts or diversions

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Nuclear Forensics Methodology

Analytical Methods
taken from:
- Safeguards
- Material Science
- Isotope Geology

Data →

- Isotopic Composition
- Elemental Composition
- Impurities
- Macroscopic appearance
- Microstructure
- Decay Products

Information

Exogenic
requires reference data

Place of Production
Last Legal Owner
Smuggling Route

Endogenic
self-explaining

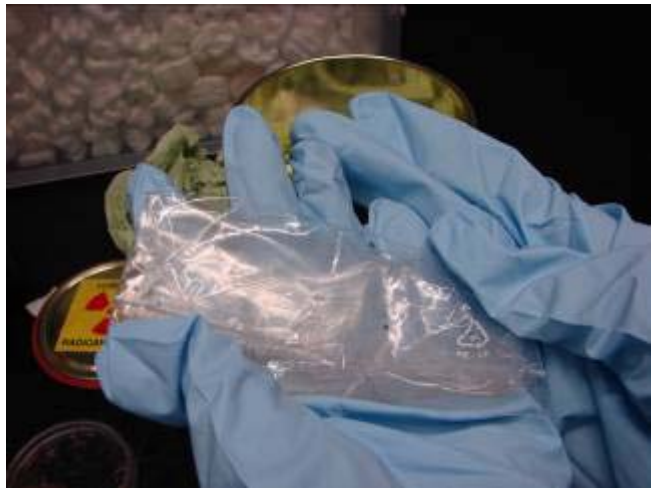
Age
Intended Use
Production Mode

Example Lauenförde -Chronology

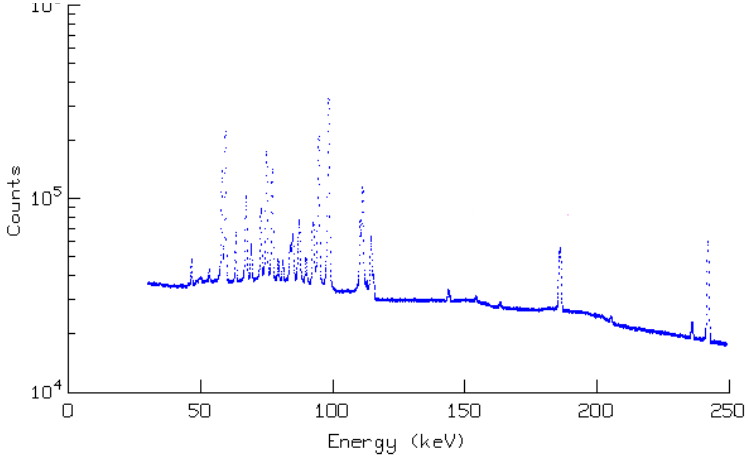
- 22. February 2007 Pellets found in garden
- 28. February 2007 Ministry for Environment (Niedersachsen) asks for support by ITU
- 03. March 2007 Samples arrive at ITU
- 05. March 2007 1. Intermediate Report (first clues)
- 09. March 2007 2. Intermediate Report (all conclusions)
- 10. Mai 2007 Final Report (full details)

Investigation in the Laboratory

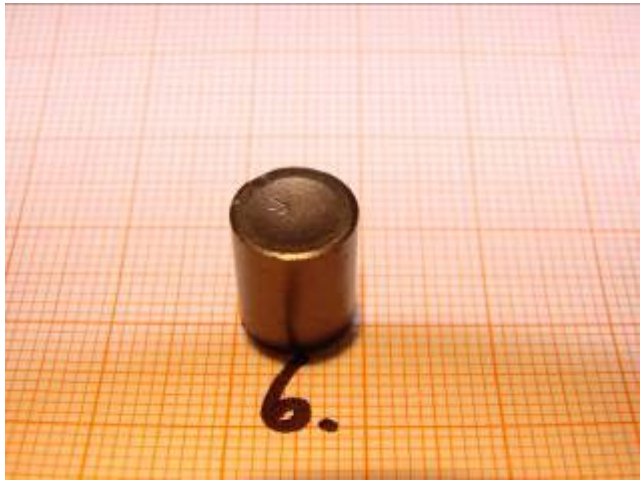
Unpacking



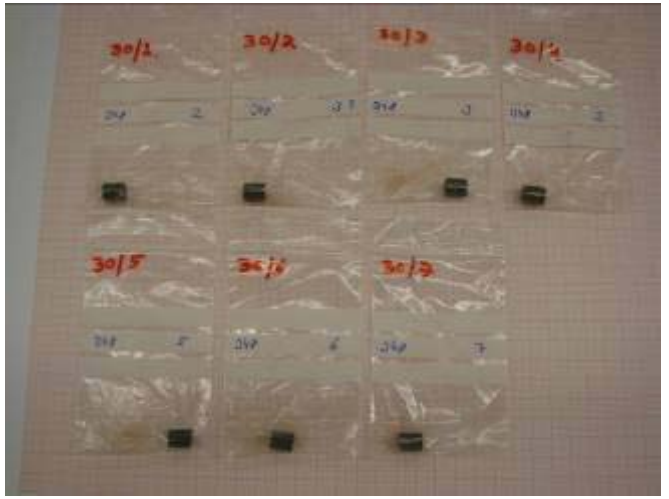
Non-destructive measurement



Visual Inspection



Homogeneity Testing



Investigation in the Laboratory

Isotopic Composition

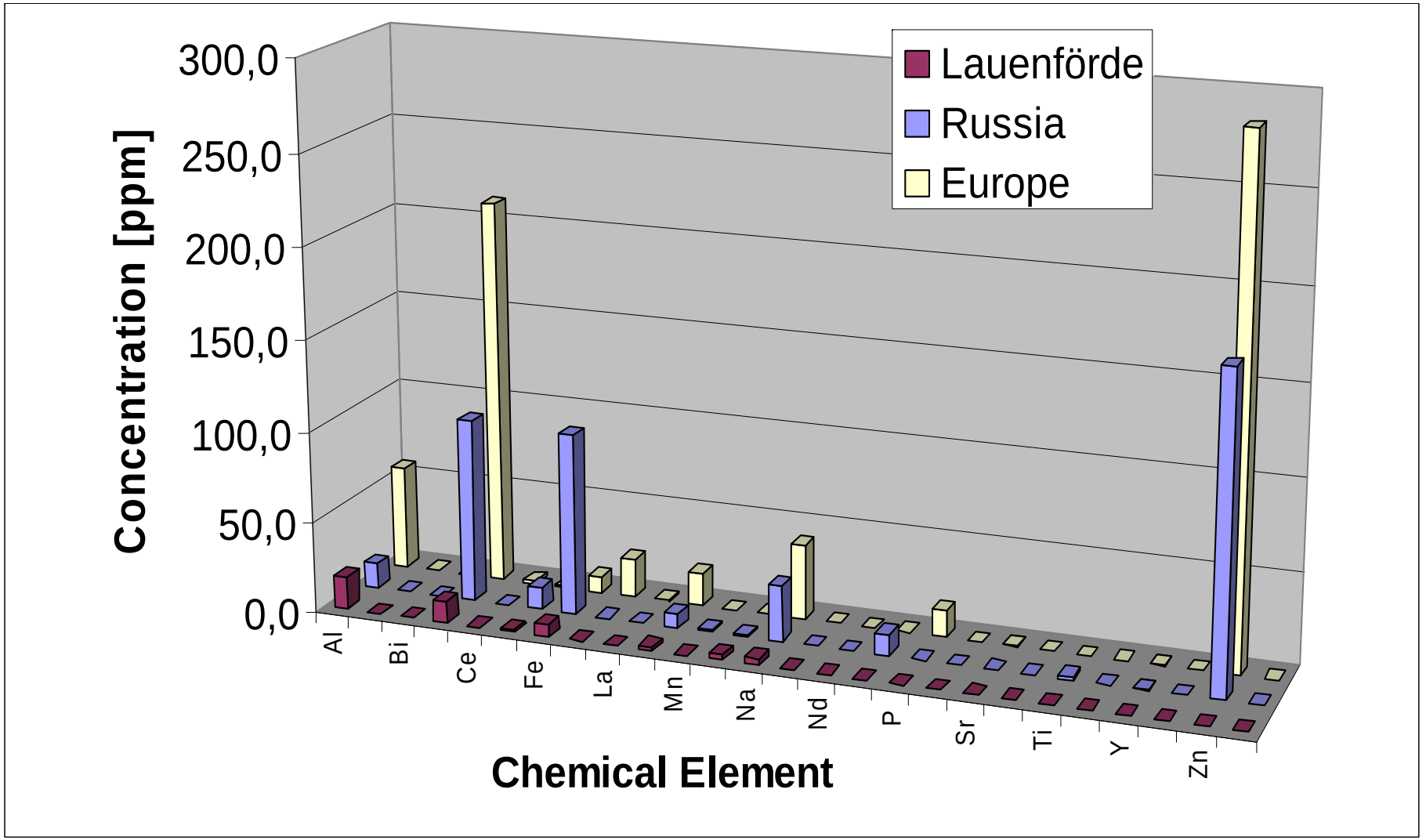
measured by TIMS

	U-234	U-235	U-236	U-238
Isotope Abundance (Mass%)	0,029 4 %	3,455 %	0,005 2 %	96,511 %
Uncertainty	0,000 3 %	0,004 %	0,000 1 %	0,003 %

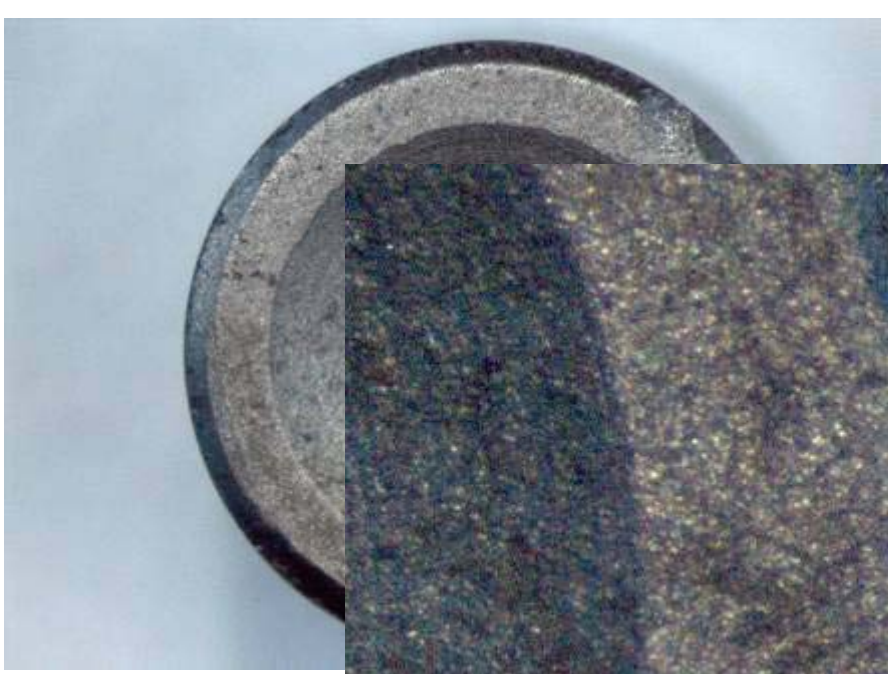
measured by MC-ICP-MS

	U-234	U-235	U-236	U-238
Isotope Abundance (Mass%)	0,029 3 %	3,459 0 %	0,005 0 %	96,506 7 %
Uncertainty	0,000 2 %	0,002 0 %	0,000 1 %	0,003 0 %

Chemical Impurities



Investigation in the Laboratory



Optical Microscopy
Pellet Geometry

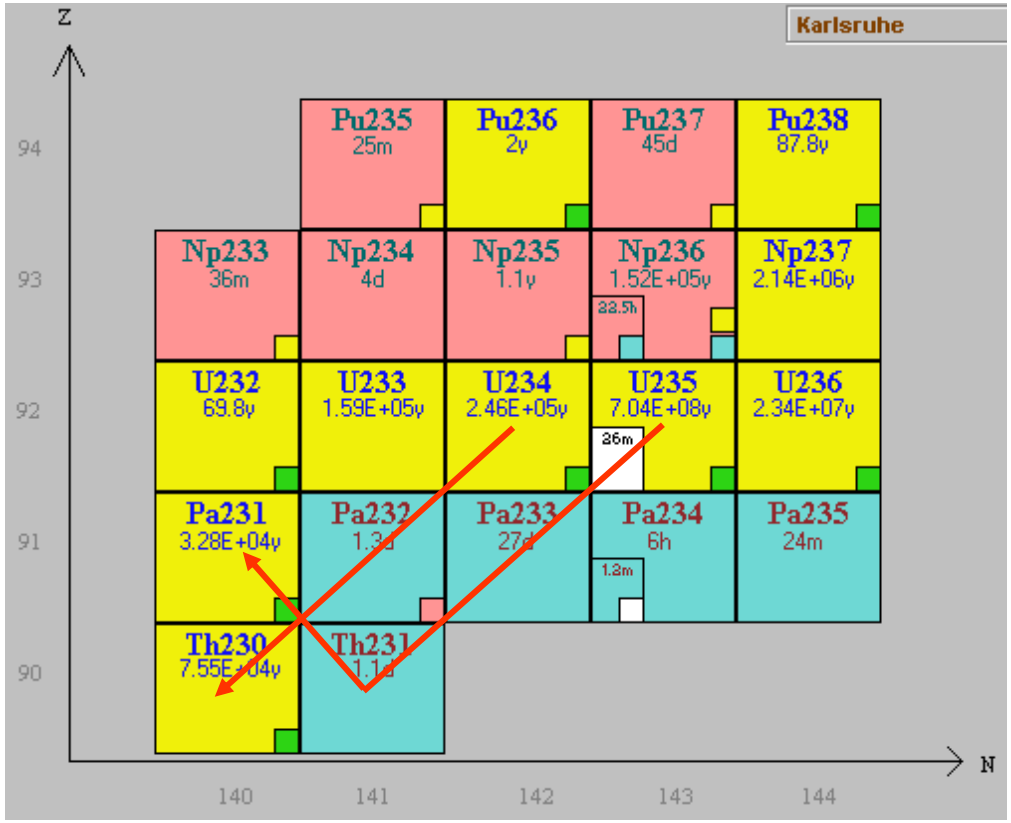
Database Query – Enrichment, Geometry

		Messung			Datenbank [1]		Datenbank [2]	
		Mittel-wert	StDev		Nominal-wert	Toleranz	Nominal-wert	Toleranz
Durchmesser	mm	9.26	0.02		9.11	0.02	9.11	0.02
Dishing Durchmesser	mm	**6.71**	**0.08**		**6.7***	**0.3***	6.73	0.05
Dishing Abstand (Land)	mm	**1.22**	**0.16**		**1.2**	**0.3**	1.2*	0.1*
Chamfer Breite	mm	**0.44**	**0.04**		**0.4**	**0.2**	*0.61*	*0.05*

Siemens (RBU) Brennelementfabrik Hanau

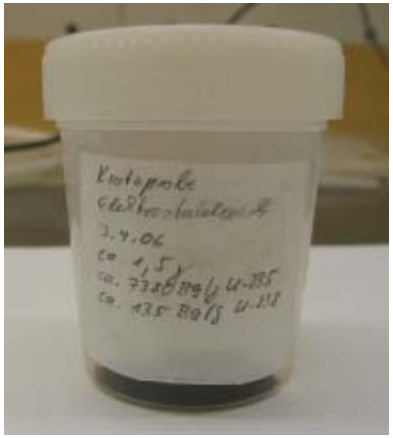
Age Determination

- Radioactive decay as built-in chronometer
- Last chemical separation Nov./Dec. 1990
- Pellet production campaign Feb./March 1991
- Fall 1991 Upgrade of physical protection at RBU plant

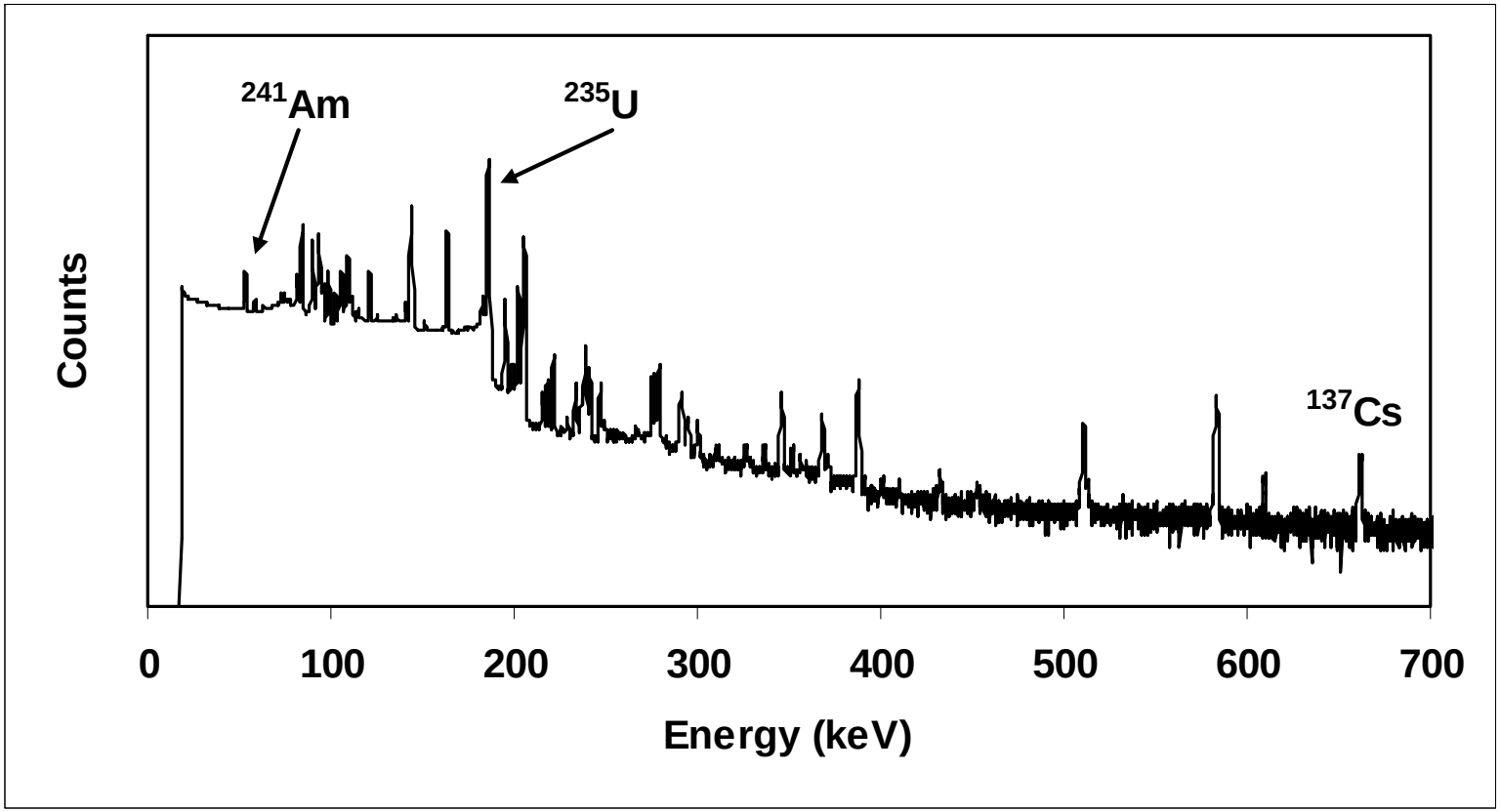


Example 2 - Hennigsdorf

- Detected 30 March 2006
- First measurement by TÜV Rheinland showed 90% enriched uranium (50 g)
- 1,5 g sample scraped off and sent to ITU



Gamma Spectrometry



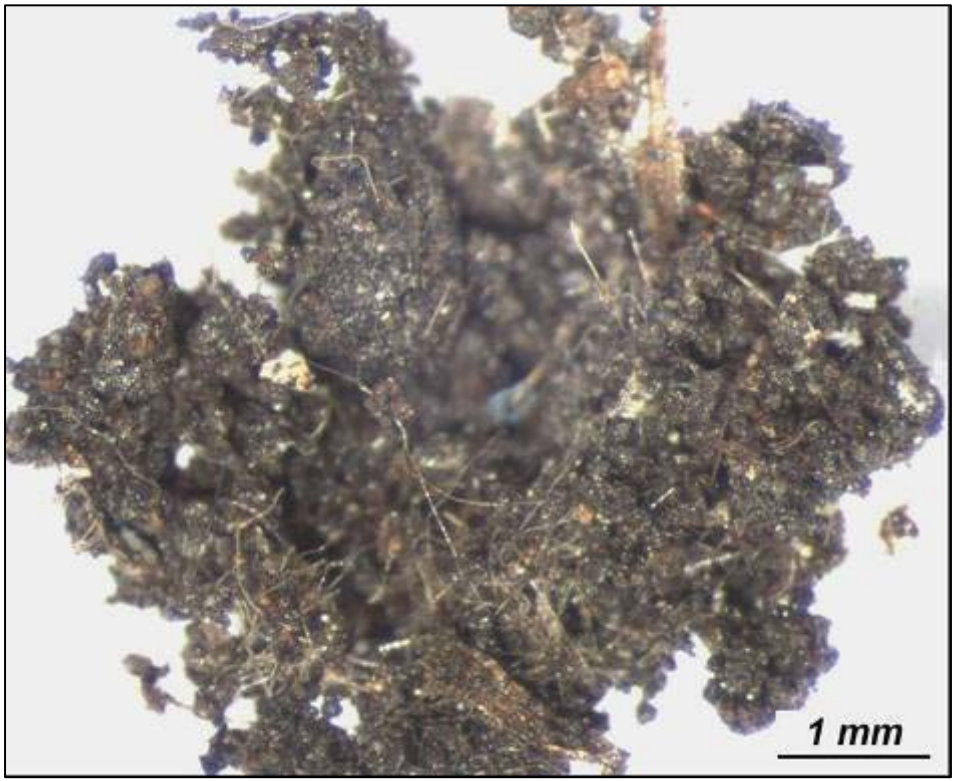
Uranium contaminated with very small amounts of ^{241}Am and ^{137}Cs

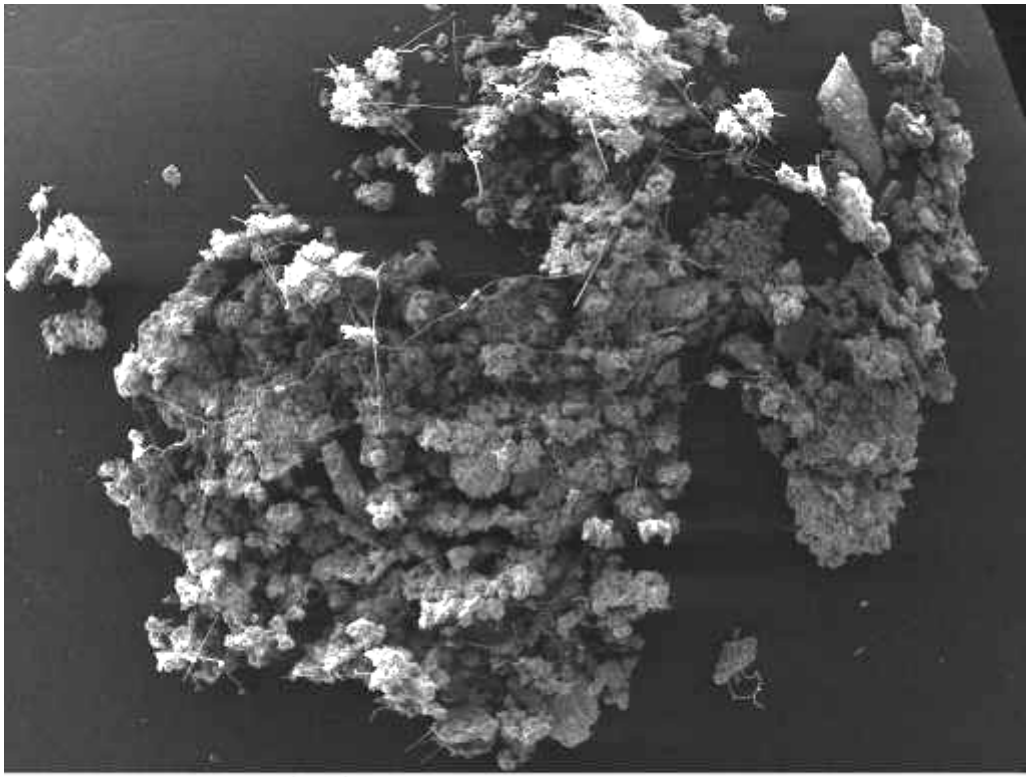
Isotopic Composition

Technique	^{233}U	^{234}U	^{235}U	^{236}U	^{238}U
TIMS	-	0.964 8 ± 0.000 7	88.878 ± 0.060	0.345 0 ± 0.000 4	9.812 ± 0.004
MC-ICP-MS	0.000 047 ± 0.000 001	0.964 1 ± 0.000 9	88.876 ± 0.010	0.346 4 ± 0.000 8	9.813 ± 0.009

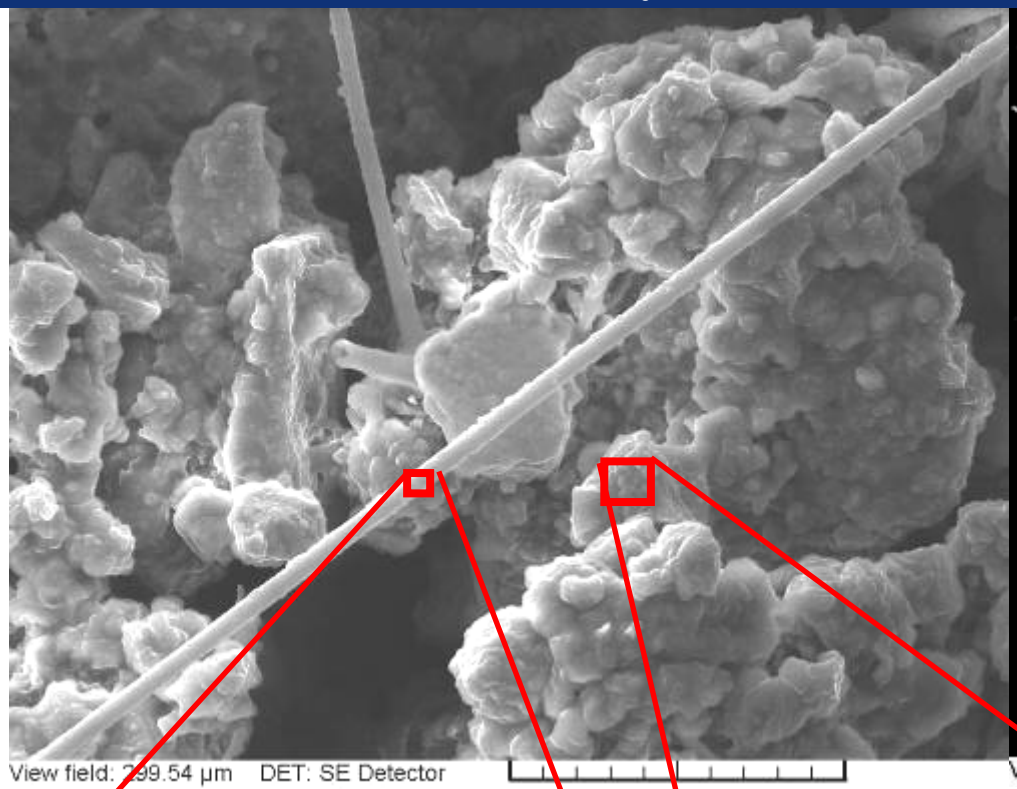
Uranium Content: 9.95 % (mass fraction)

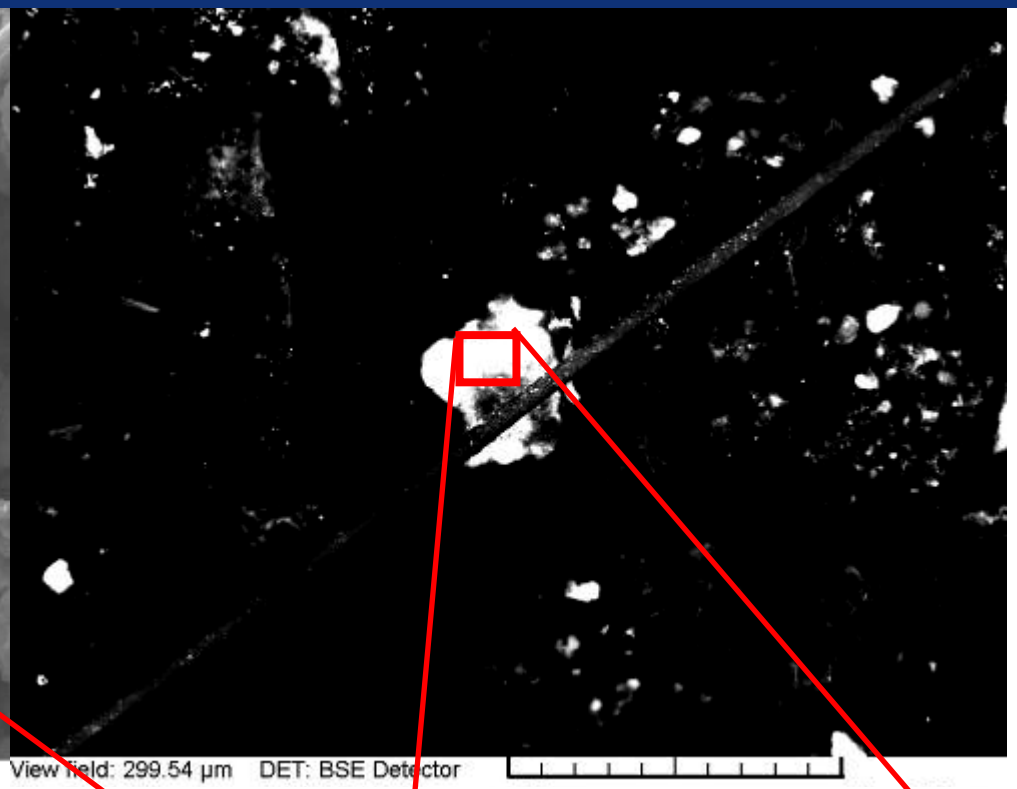
Microscopy

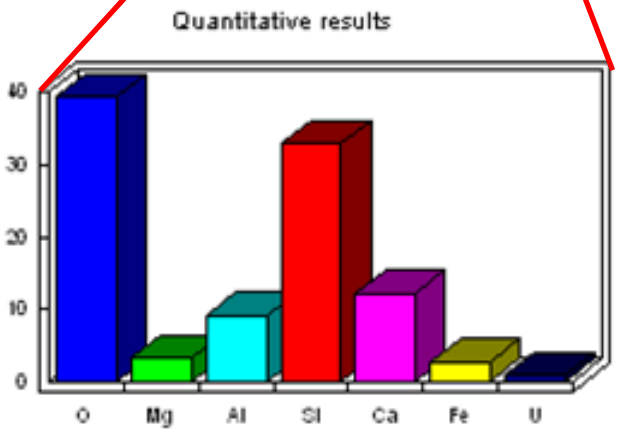


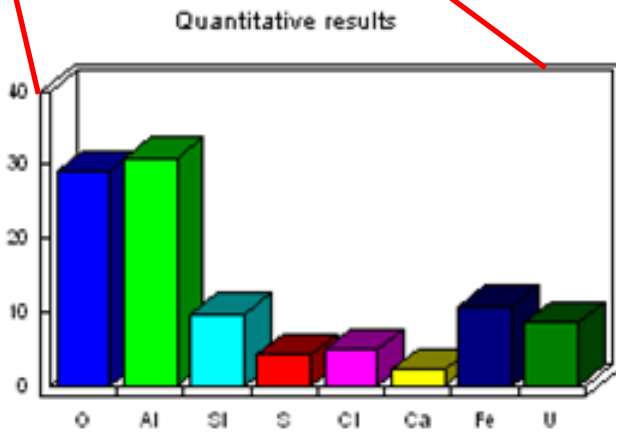


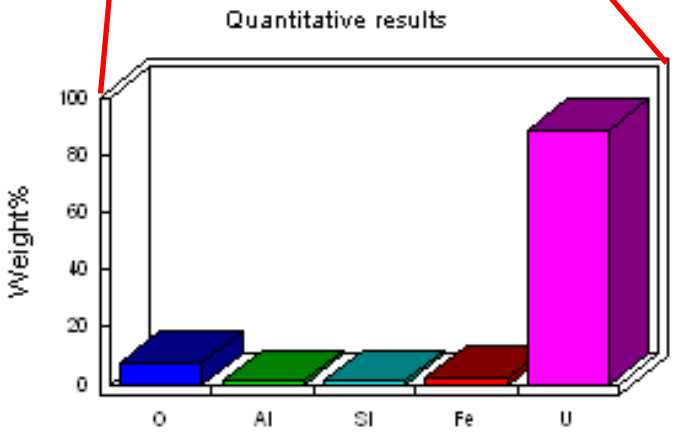
Age Detemination: Production date Dec. 1999 (± 4 months)


View field: 299.54 µm DET: SE Detector


View field: 299.54 µm DET: BSE Detector


Quantitative results
40
30
20
10
0
O
Mg
Al
Si
Ca
Fe
U


Quantitative results
40
30
20
10
0
O
Al
Si
S
Cl
Ca
Fe
U


Quantitative results
Weight%
100
80
60
40
20
0
O
Al
Si
Fe
U

Research Reactors (in Russia) using 90% enriched uranium

Facility	Operator	Fuel	Power (MW)
IR-8	Kurchatov Institute, Moscow	UO_2 + Al	8
BR-10	IPPE, Obninsk	UO_2 – PuO_2	10
BOR-60	NIIAR, Dimitrovgrad	U or Pu	60
MIR-M1		UO_2 + Al	100
SM-3		UO_2 + Cu	100
IVV-2M	NIKIET, Yekaterinburg	UO_2 + Al	15
IRT-T	TPI, Tomsk	UO_2 + Al	6
IRT-MIFI	MIFI, Moscow	UO_2 + Al	2.5
VVR-M	PNPI, Gatchina, St.Petersburg	UO_2 + Al	18

Example 2 - Conclusions

Sample	^{234}U	^{235}U	^{236}U	^{238}U	Information
Find-16 + Czech HEU	1.079	87.775	0.211	10.937	ITU
Round Robin HEU	0.960	89.888	0.679	8.472	ITU
Bulgaria HEU	1.18	72.66	12.13	14.04	LLNL
Georgia-2006		89.451			New York Times
Find-27 (this work)	**0.965**	**88.878**	**0.345**	**9.812**	**ITU**

- Chemically impure material, high Al content
- 88.9% enriched in ^{235}U
- Traces of ^{137}Cs and ^{241}Am
- Most likely research reactor fuel
- Scrap

Nuclear forensics

- Discipline between science, law enforcement,
- Uses systematic approach for analysis and attribution
- Benefits from Reference Data
- Provides clues on the origin of the material
- Assures sustainability in combating illicit trafficking
- Calls for International Co-operation
- Methodology applicable in other areas

ITWG Nuclear Forensics

IAEA International Atomic Energy Agency

Exercise- 1

After a seizure of radioactive material, the measurement team called to the incident site typically performs high resolution gamma spectrometry. What spectra can they expect for a measurement carried out with the material still being inside the transport container (10 mm Steel and 5 mm lead) for the following material ?

a) Freshly separated natural uranium ?

b) Natural uranium separated 1 year ago ?

c) Freshly separated highly enriched uranium (1.08% ^{234}U; 93.34% ^{235}U; 0.2% ^{236}U; 5.38% ^{238}U) ?

d) Highly enriched uranium (1.08% ^{234}U; 93.34% ^{235}U; 0.2% ^{236}U; 5.38% ^{238}U) separated 50 years ago ?

Exercises

Examples of application of NUCLEONICA to problem related to uranium (in illicit trafficking and nuclear forensics)

- Nuclide explorer
- Nuclide mixture (virtual nuclide)
- Decay engine
- Gamma spectrum simulator

Exercise- 2

If you want to determine the age of a uranium sample, which parent/daughter pairs can you use in principle?

Exercise- 3

One of the methods safeguards inspectors use to verify compliance with treaty obligations is "environmental sampling", i.e. the collection of particles within (or outside) nuclear facilities using swipe sampling. Uranium particles in such swipe samples are typically analyzed for their isotopic composition. However, the question arises whether age determination on such small particles is also possible.

Exercise- 3

Assume the minimum number of daughter atoms required for age determination is 10000. A typical UO_2 particle on such swipes has a diameter of 1 μm. The density of UO_2 is 10 g/cm^3.

a) Can Age determination be performed on such particles if the isotopic composition is natural (0.0055% ^{234}U; 0.7% ^{235}U) ?

b) Is age determination possible for particles of highly enriched uranium (1.08% ^{234}U; 93.34% ^{235}U) ?

$V = 4/3\ \pi\ r^3$

$U/UO_2 = 0{,}8815$

$N_A = 6.022 \cdot 10^{23}\ mol^{-1}$